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Diffraction Enhanced X-Ray Imaging of Human Articular Cartilage

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Beamline(s): X15A

Introduction: Destruction and loss of articular cartilage is one of the hallmarks of osteoarthritic disorders. Imaging techniques commonly used to assess articular cartilage are based on x-ray, ultrasound or nuclear magnetic resonance (1,2). Conventional radiography has the highest spatial resolution and is the initial and most practical of the imaging methodologies. However, because cartilage is not visible with conventional radiography, the radiographic evaluation is based on narrowing of the joint space between the ends of the bones that occurs as the cartilage is destroyed. Hence, conventional radiography is sensitive only in cases of advanced disease. Diffraction Enhanced Imaging (DEI) is an x-ray technique that derives contrast from x-ray refraction and extinction in addition to the absorption of conventional radiography. In the present study we have shown that, with DEI, we can detect the articular cartilage of both disarticulated and intact human knee and ankle joints.

Methods and Materials: Human knee and ankle cartilages and intact joints used for this study were obtained with institutional approval either from donors through the Regional Organ Bank of Illinois or from patients undergoing total knee replacements. All experiments were performed at the X15 beamline at the NSLS, BNL. The basics of DEI are described elsewhere (3,4). Briefly, the method used highly collimated x-rays prepared by x-ray diffraction from perfect silicon crystals. These collimated x-rays consist of a single x-ray energy and are used as the beam to image the object. For DEI, a third crystal (analyzer) is placed between the subject to be imaged and the detector. If this crystal is rotated through the Bragg condition for diffraction, the intensity from the crystal traces out a profile that is called the rocking curve. This profile is roughly =triangular and has peak intensity close to that of the beam intensity striking the analyzer. The character of the images obtained changes depending on the setting of the analyzer.

Results: With “conventional” synchrotron radiography the articular cartilage was not visible. However, when DEI was used, normal articular cartilage was apparent in both disarticulated and intact knee and ankle joints as homogeneous and of moderate density. Cartilages displaying grossly visible degenerative changes characteristic of osteoarthritis had DE images with contrast heterogeneities that corresponded to the degree and location of the grossly visible lesions. Furthermore, in the intact knee and ankle joints, the cartilage was visible even through the superimposed soft tissues, such as skin and connective tissue of the joints (Figure 1).

Conclusions: We have shown that it is possible to derive high resolution images of human articular cartilage on a radiograph using DEI. This recent technology could provide scientists and clinicians with information about the internal structure of normal and degenerative joints. Most important, the potential is great for DEI to be used to identify early changes in cartilage structure during the process of degenerative joint disease. DEI may provide a new means of early diagnosis for treatment of osteoarthritic disorders. We believe that DEI can be used as part of a new x-ray generation in research as well as in clinical radiology, especially in skeletal x-ray and other areas where soft tissue contrast needs to be enhanced.

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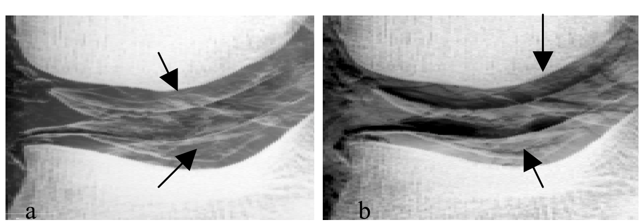

Figure 1. DE images depicting the articular cartilage (arrows) and menisci (between cartilage plates) of the medial region of the human knee joint at the top of the rocking curve (a) and at –3.6 of the rocking curve (b).